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PREDICTED VIBRATION AND ACOUSTIC ENVIRONMENTAL STUDY

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Predicted Vibration and Acoustic Environmental Study

XV-5A Lift Fan

Flight Research Aircraft Program

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Advanced Engine and Technology Department
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1.0 SUMMARY

The U. S. Army XV-5A Research Lift Fan aircraft was investigated during its initial design stages to predict the vibration and acoustic environments associated with full power operation of the two engines and the three lift fans. The highest concentration of vibratory energy lies in the area immediately aft of the tailpipe during the conventional aircraft take-off mode, and in the area under the wings during the vertical or lift fan take-off mode.

Environmental data obtained from tests conducted at NASA Ames Research Center showed that the maximum expected over-all sound pressure level (SPL) in the near field during operation in either lift fan or conventional modes will be approximately 133 db. Calculations of material fatigue life indicated that no structural failures would occur during the design life of the aircraft as a result of the near field acoustic environment. Of the panels investigated near the areas of maximum intensity, the one with the least expected life was calculated to be at least 2.5 times the aircraft design life. The interior cockpit SPL resulting from vertical take-off mode is expected to be within the guide specification MIL-A-8806 according to the data taken at Ames.

Vibration levels associated with non-afterburning fighter aircraft do not vary significantly as a function of weight or size, and levels obtained from the Century-series aircraft do not show large amplitude displacements or high acceleration values. Therefore, estimated vibration levels on the XV-5A solid structure will probably not exceed $\pm$ 3 g or 0.55 inches double amplitude displacement, whichever is less, for all flight conditions. Vibration amplitudes occurring during steady-state conditions are not expected to exceed 0.0088 inches double amplitude displacement or $\pm$ 3 g, whichever is less. In addition to the above conclusions, for purposes of completion, the criteria for the XV-5A vibration qualification test is included herein.

2.0 INTRODUCTION

This report is a summary of vibratory and acoustic investigations used for the design and selection of reliable structures and equipments for the U.S. Army XV-5A Lift Fan Research Aircraft. The XV-5A is a vertical take-off and landing (VTOL), two seat, twin-engine, turbojet powered aircraft. Propulsion for VTOL operation is accomplished by thrust augmentation using three General Electric lift fans.

Data presented generally describe the vibratory and acoustic environments obtained from certain Century-series aircraft, as well as the results of ground operation of the two General Electric J-85 engines (without afterburner) and the three lift-fans. The ground operation data were obtained from static test bed operations at NASA Ames Research Center, Moffett Field, California.

3.0 DISCUSSION

3.1 ORIGINAL ESTIMATES

An estimate of maximum environmental acoustic noise and vibration of the primary aircraft structure was made to aid in the design and selection of reliable structures and equipments for the XV-5A aircraft. The basis for these estimates has been included.

3.1.1 Original Estimated Vibration of Primary Structure

The significant vibratory energy that will occur in the XV-5A aircraft can be divided into two classes, sinusoidal and random. Sinusoidal vibration will occur as a result of inherent unbalance that exists in all rotating equipments, such as wing and pitch fans, engines, electrical power sources, etc. A random type of vibration will occur as the result of structural vibration modes that are stimulated by aerodynamic turbulence, take-off and landing shocks and acoustic noise. This type of vibration consists of quasi-sinusoids whose amplitudes vary in a non-sinusoidal fashion.

Extensive vibration data are not available on aircraft of similar gross weight. However, observations by WADC Environmental Laboratory personnel, (Reference 1), indicate that vibration levels do not vary significantly as a function of aircraft weight or size. The predominant frequencies of vibration may vary, but in general, similar amplitudes of vibration can be expected for the same flight conditions.

Vibration levels measured on Century-series aircraft were plotted and evaluated with regard to flight conditions, (References 2, 3, 4 and 5). Interpretation of these data is based on the lower performance requirements of the XV-5A aircraft.

The smoothed response envelope of the maximum vibration levels estimated for solid structure of the XV-5A aircraft is presented in Figure 1.

Estimated vibration levels of solid structure do not exceed $\pm$ 3g or 0.55

inches displacement double amplitude, whichever is less, for all flight conditions. Vibration amplitudes occurring during steady-state conditions are not expected to exceed 0.0088 inches displacement double amplitude or $\pm$ 3g, whichever is less.

High amplitude, low frequency vibrations result from transient conditions associated with take-offs, landings and gusts.

3.1.2 Original Estimated Acoustic Pressures

The extreme acoustic pressures that are expected to influence aircraft structure will occur during take-off conditions. Vertical take-off will provide sound pressures that are the result of wing and nose fan operation in addition to noise generated by the high velocity gas driving these fans. Conventional take-off will produce high acoustic levels as a result of the shearing of the jet exhaust, issuing from the tailpipe, with the surrounding air. Estimated levels representing both conditions are presented. However, as noted in Section 4.0, these original estimates were considerably higher than those actually obtained from ground test of the complete propulsion system, and therefore subsequent calculations were based solely on the ground test data.

Measured sound pressure levels (SPL) resulting from the operation of a full scale wing fan driven by a J-85 engine (Reference 6) have been modified to simulate the XV-5A vertical take-off mode of operation. Estimates of acoutic levels resulting from a conventional take-off are based on data measured in, or near other aircraft, (References 7 and 8), and modified for differences in engine characteristics.

Figures 2, 3 and 4 present respectively, the original estimated octave band sound pressure levels as a function of vertical or normal take-off conditions for the wing trailing edge, lower empennage, and the fuselage area adjacent to the cockpit. Figure 5 presents the original estimated cockpit levels for the two take-off conditions as compared to the target Specification MIL-A-8806.

The estimated octave sound pressure levels indicate the aircraft will experience the most extreme pressures during vertical take-off. Empennage structure will be the sole exception that will be influenced more strongly by pressures that occur during normal take-off. Noise produced in the lift fan mode will contain many discrete frequencies that will occur in the three highest octaves. In general, the estimated levels are quite low and will probably cause few problems. Possible exceptions may occur in the event a particular equipment resonance coincides with the discrete fre-

quencies produced by engine operation.

Cockpit levels appear to be below the guide specification MIL-A-8806, with the exception of the four highest octaves occurring during VTOL operation. Conformance to the specification can be effected as required.

Cockpit noise estimates are based on an adequately sealed enclosure that restricts direct entry of external radiation. An increase in the estimated levels would result if this condition were not met.

3.2 GENERAL ELECTRIC LIFT-FAN NEAR-FIELD NOISE DATA

A noise measurement survey of the General Electric lift-fan system designed for use in the Ryan XV-5A aircraft was conducted on February 3, 1962, at Moffett Field, California. The test set-up simulated the XV-5A propulsion system. Results of the near-field portion of the measurement are documented herein.

Data was recorded at four near-field microphone positions (locations given in Table 1, and as shown in the attached photographs, Figures 6, 7 and 8). The microphones were Altec 21BR150 in Positions 1 and 4, and 21BR200 in Positions 2 and 3. Data was recorded simultaneously from two microphones on an Ampex 601-2 two-channel tape recorder. Acoustic calibration was made by means of a General Radio transistor oscillator and calibrator speaker. All microphones were equipped with Altec 170A wind screens, however, wind noise may still have been appreciable.

Data was reduced in 6% bandwidth (1/12 octave) by means of a Bruel and Kjaer type 2107 frequency analyzer. Measured sound pressure levels (SPL), including response corrections, are given in Table 2 for the fan fundamental frequency and all identifiable harmonics. The measured near-field SPL's include the influence of the reflecting surfaces in the area (test vehicle, pavement).

Some instrumentation difficulties were encountered during the test, as noted by the presence of gaps in the data of Table 2. No spectral plots of the acoustic data were available for inclusion in this report.

3.3 PRELIMINARY ACOUSTIC FATIGUE ANALYSIS

An analysis was made to avoid the possibility of wing fan damage that could occur from the ingestion of material, failing as a result of sonically-induced structural fatigue. Panels located in areas of maximum environmental pressures, (those adjacent to the fan) have been examined.

A semi-empirical analysis was pursued in the absence of available test data relating to identical structures. Initially, panel frequencies, and environmental acoustic pressures occurring at these frequencies were determined. Fatigue data resulting from the exposure of similar structure to acoustic pressure was utilized. These data were then used as a basis for determining the fatigue life expectancy of the proposed structure, by calculating the panel stress as a ratio of the known panel stress, considering the difference in panel sizes, thickness, fixities, and applied acoustic pressures at the fundamental panel frequencies. The expected fatigue life was determined by applying the stress ratio to the relevant S-N curve.

Environmental pressures used for pusposes of this analysis are measured values, (Reference 9). Calculated panel modes lie within the frequency range of the maximum acoustic energy. It was assumed that 133 db would be the most extreme sound pressure level (SPL) existing at the panel mode which would produce the greatest panel stress for 200 hours. Stress ratios were calculated for flap, aileron and outboard-fan panels, relative to the stress occurring in a similar aircraft type panel, from which test data are available, (Reference 10). Consistent with previous experience, a linear pressure-stress relationship was assumed. Complexity of the forward panel, inboard and adjacent to the fan, necessitated a somewhat different approach. Static load-stress calculations, (Reference 11), were utilized and modified to account for a dynamic load factor based on estimated structural damping of 2.5% of critical damping. Absolute stress levels were estimated based on a maximum SPL of 133 db. Panel life was estimated in each case by applying the calculated stress response to the appropriate S-N curve. The most critical configurations selected in each case were:

<u>Aileron Panels</u>

Panel Size - 6 inches by 12 inches

Material - Magnesium

Gauge - .020 inches

Assumed SPL duration - 200 hours wing fan operation

Magnesium is unstable and prediction of fatigue life is unreliable when oxidation occurs. Estimated service life of the panel is approximately 2-1/2 times the aircraft design life.

Flap Panels

Panel size - 6 inches by 8 inches

Material - Aluminum - 2024

Gauge - .025 inch

Assumed SPL duration - 200 hours wing fan operation

Estimated environmental skin temperature - 375°F

Estimated service life of the panel is approximately 30 times the aircraft design life.

Skin Panel, Forward and Inboard of Fan

Effective panel size - 6 inches by 17.5 inches, chem-milled and waffle-stiffened

Material - Aluminum - 2024

Gauge - Waffle .035 inches - waffle ribs .25 inches - stiffeners .10 inches

Assumed SPL duration - 200 hours wing fan operation

Estimated service life of the panel is approximately 25.6 times the aircraft design life.

Skin Panels Outboard of Fan

Panel size - 8 inches by 24 inches

Material - Aluminum - 2024

Gauge - .030 inch outboard to .060 inch inboard

Assumed SPL duration - 200 hours wing fan operation

Estimated service life of the panel is approximately 29 time the aircraft design life.

3.4 VIBRATION QUALIFICATION TEST

As a basis for insuring reliable operation for the desired design life, all equipments (including sub-assemblies on resilient mounts which are attached directly to engine or primary structure of the XV-5A aircraft) to be qualified, shall be qualification tested as described below.

The following procedure shall be repeated with vibratory excitation applied to each of three mutually perpendicular axes of the specimen.

The specimen shall be attached to a rigid fixture capable of transmitting the desired amplitudes of vibration. A search shall be made to establish specimen resonances in a frequency range from 5 to 500 cps. The applied amplitude of vibration shall be below those indicated on Curve ABC, Figure 9. An additional frequency scan shall be made (in the same frequency range) while the specimen is performing its design function. Amplitudes of vibration shall be 50% of those indicated by Curve ABC, Figure 9. The rate of scan shall be that specified in Figure 10. Malfunction of the specimen, as defined in the design specification and occurring during this portion of the test, shall be considered as failure to qualify.

The one or two most extreme specimen resonances, as determined by the preceding frequency scan, shall be selected. The specimens shall be vibrated at the chosen resonant frequencies, at specified temperatures, for the periods indicated in Tables 3 and 4. Amplitudes of vibration shall be those indicated by Curves ABC and A'B'C, Figure 9.

In the event that no specimen resonances are present, the specimen shall be vibrated at 42 cps and 287 cps, lift-fan and engine rotational frequencies respectively, for a period of 30 minutes at each frequency. Amplitudes of vibration shall be those indicated by Curves ABC and A'B'C, Figure 9.

In addition to the previous tests, the specimen shall be vibrated under these cycling conditions: the frequency shall be cycled from 5 to 500 and back to 5 cps in 15 minutes at a logarithmic rate as shown in Figure 10. An applied double amplitude of .012 inch, or an applied acceleration of $\pm$ 4g shall be employed, whichever is lower. Cycling time shall be as specified in Tables 3 and 4.

A thorough visual inspection and a functional check of the equipment shall be performed at the conclusion of the "cycling" portion of this test. Deterioration or change in performance of any components which could prevent the equipment from meeting service requirements shall constitute a failure to qualify for service on the aircraft.

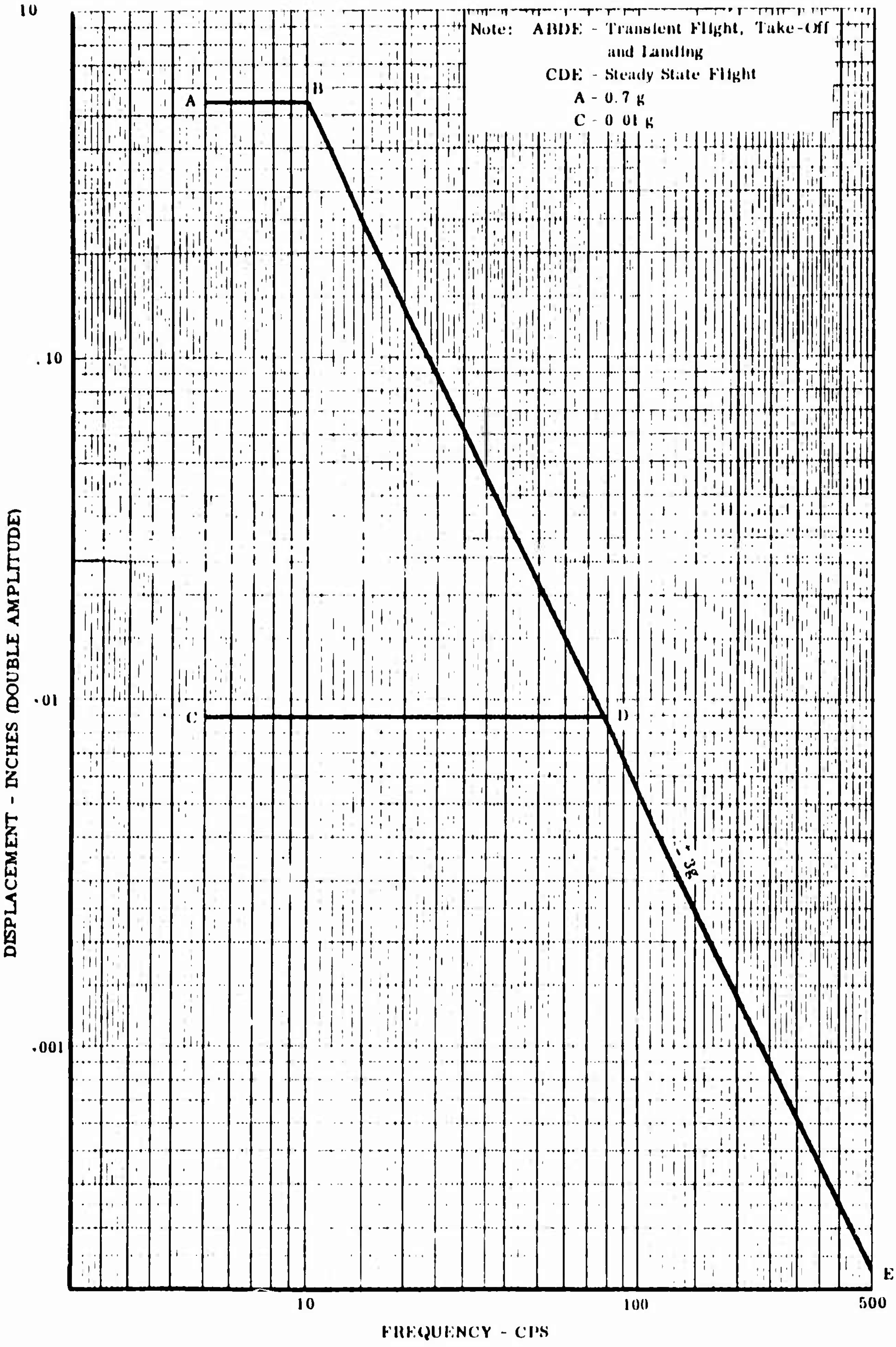

Figure 1 Estimated Maximum Vibration Environment

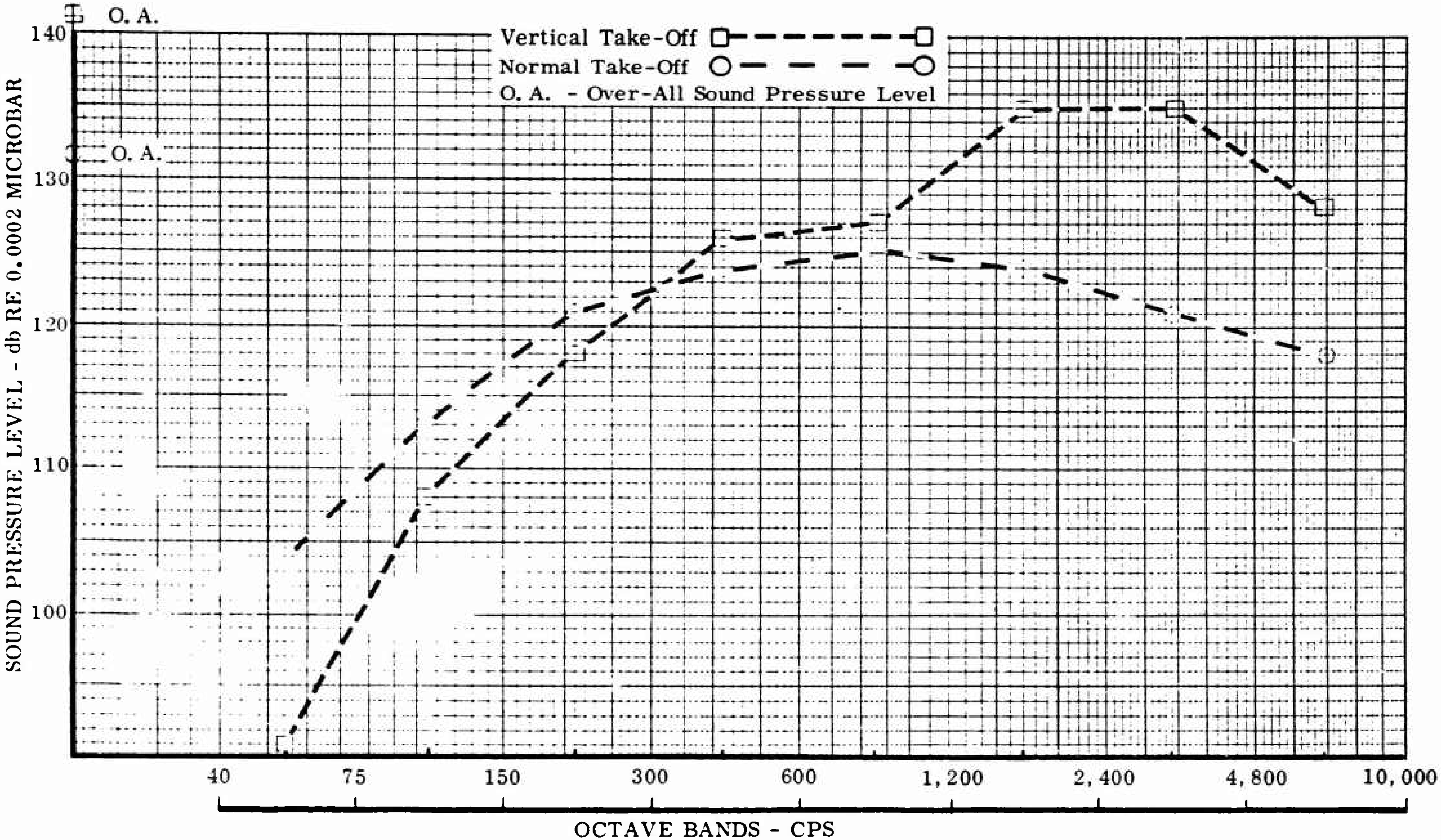

Figure 2 Estimated Octave Acoustic Pressures - Wing Trailing Edge

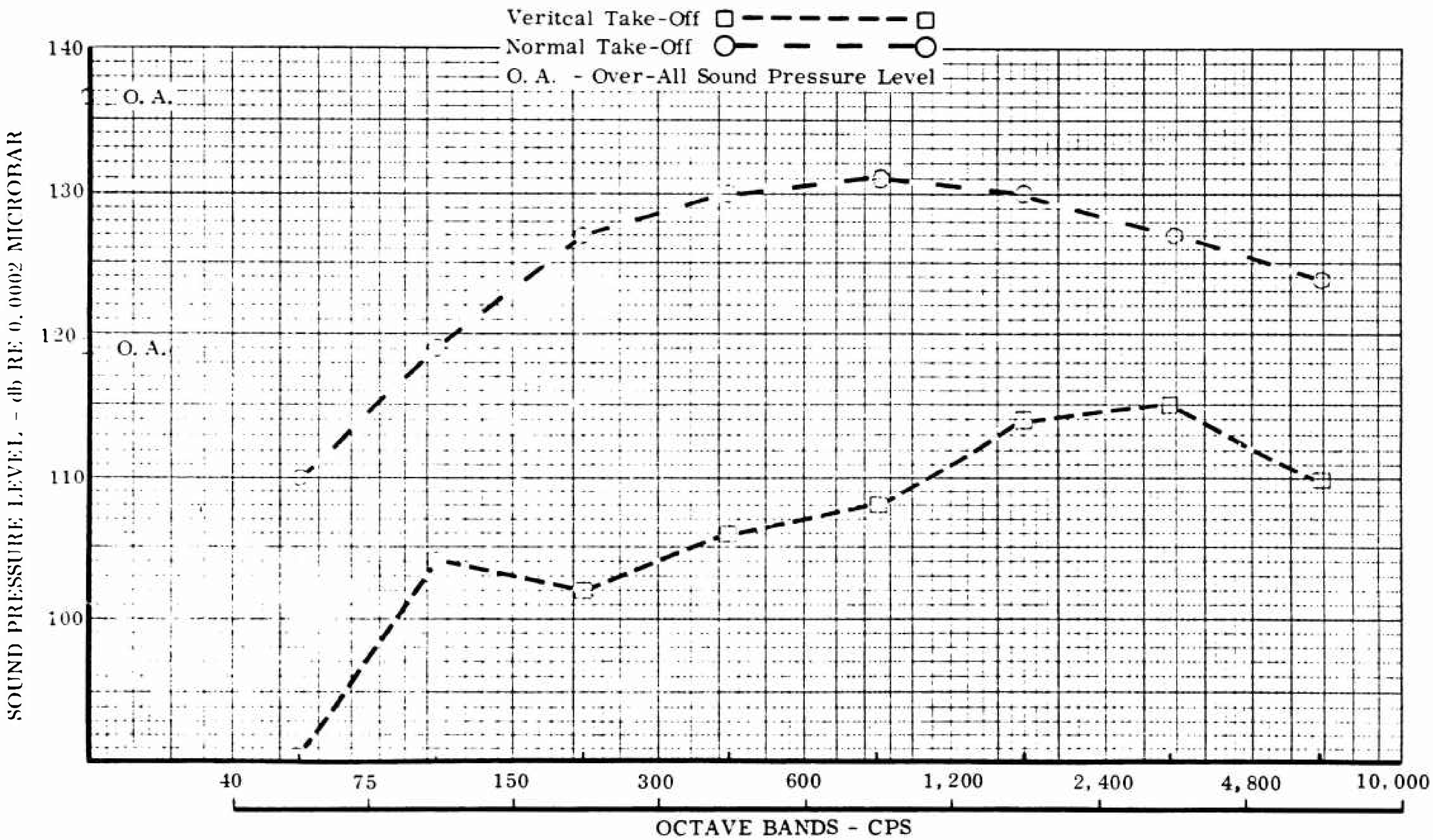

Figure 3 Estimated Octave Acoustic Pressures - Base of Empennage

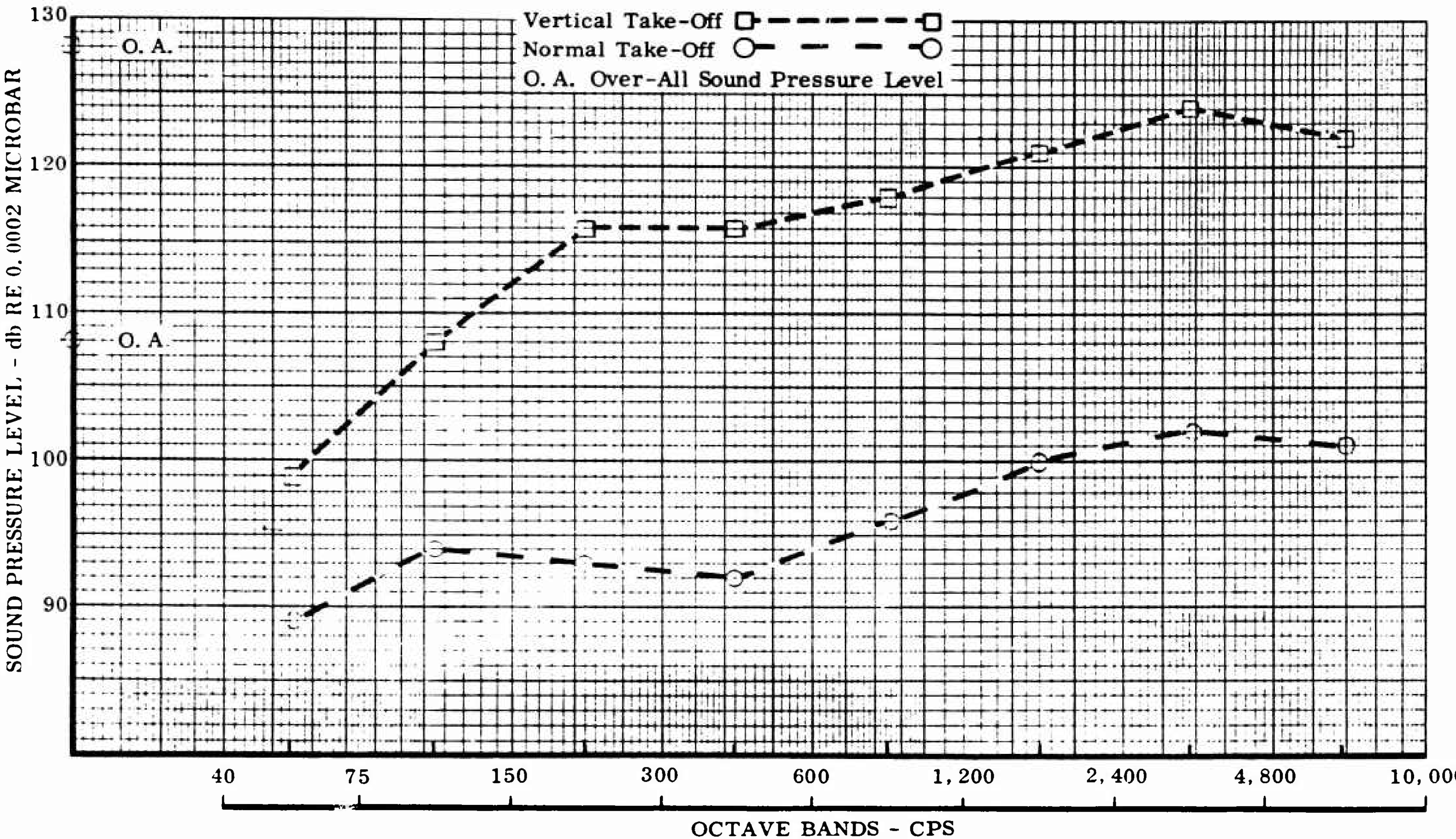

Figure 4 Estimated Octave Acoustic Pressures - Fuselage Adjacent to Cockpit

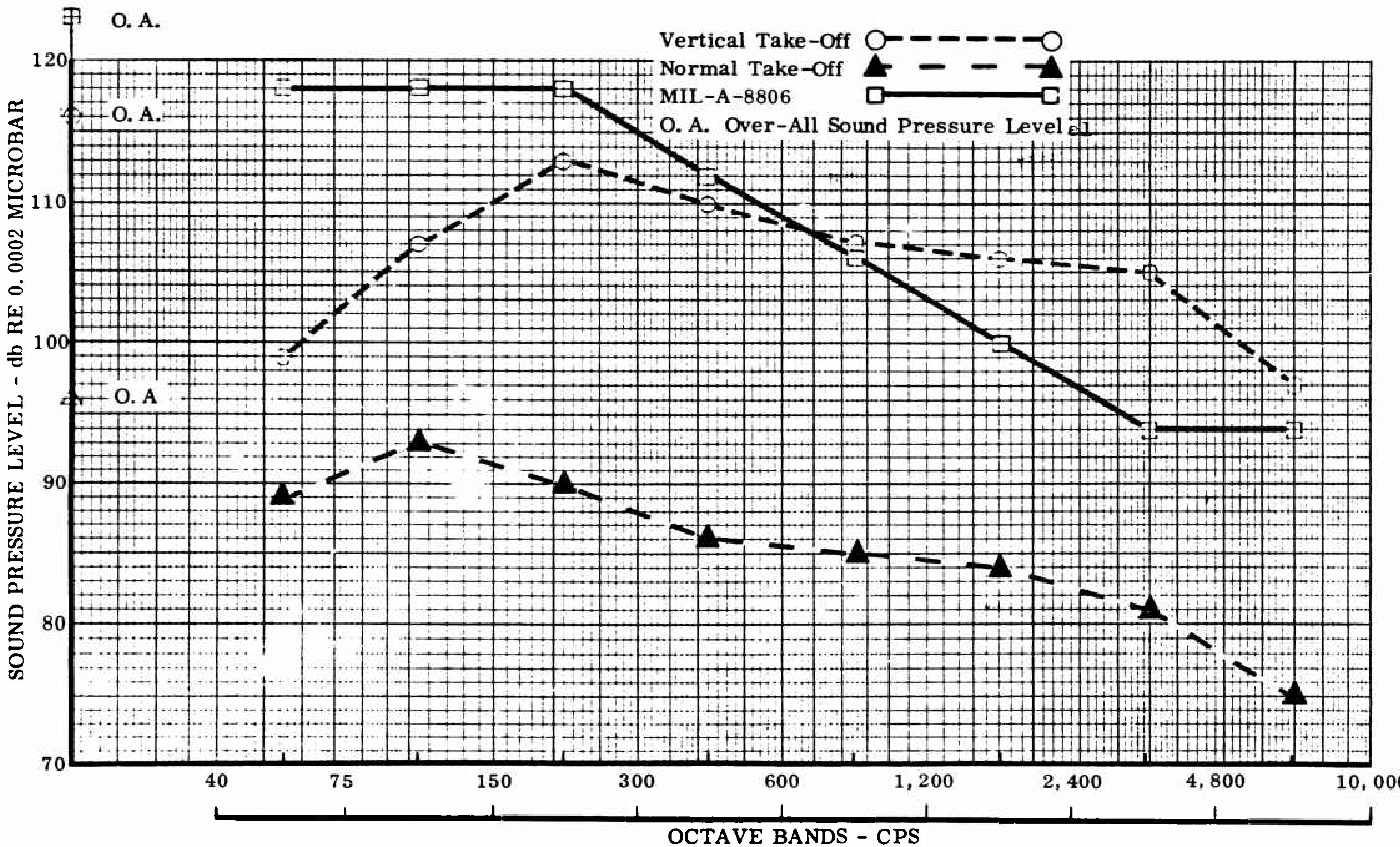

Figure 5 Estimated Octave Acoustic Pressures - Inside Closed Cockpit

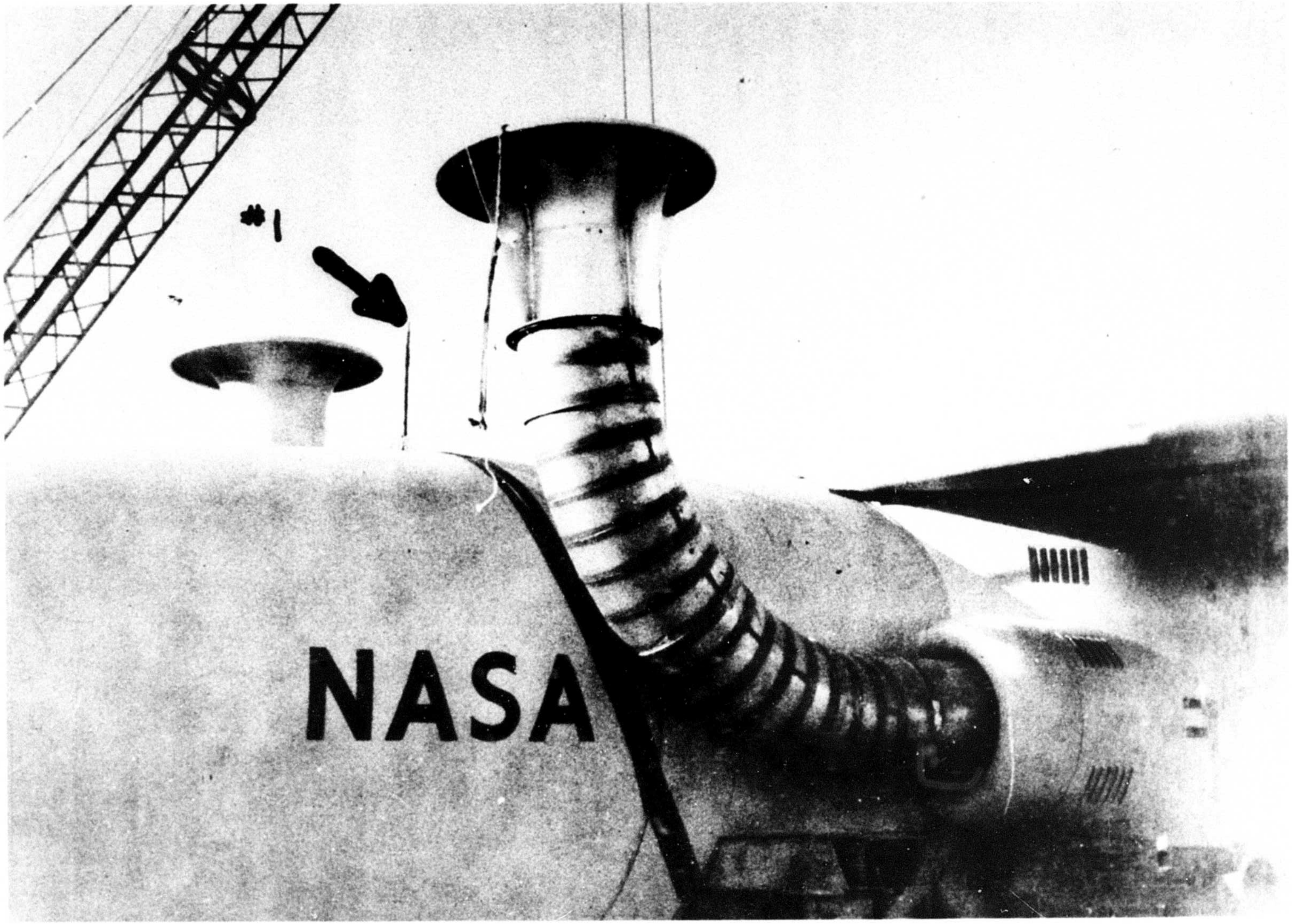

Figure 6 Microphone Location: General Electric Ground Test at NASA-Ames

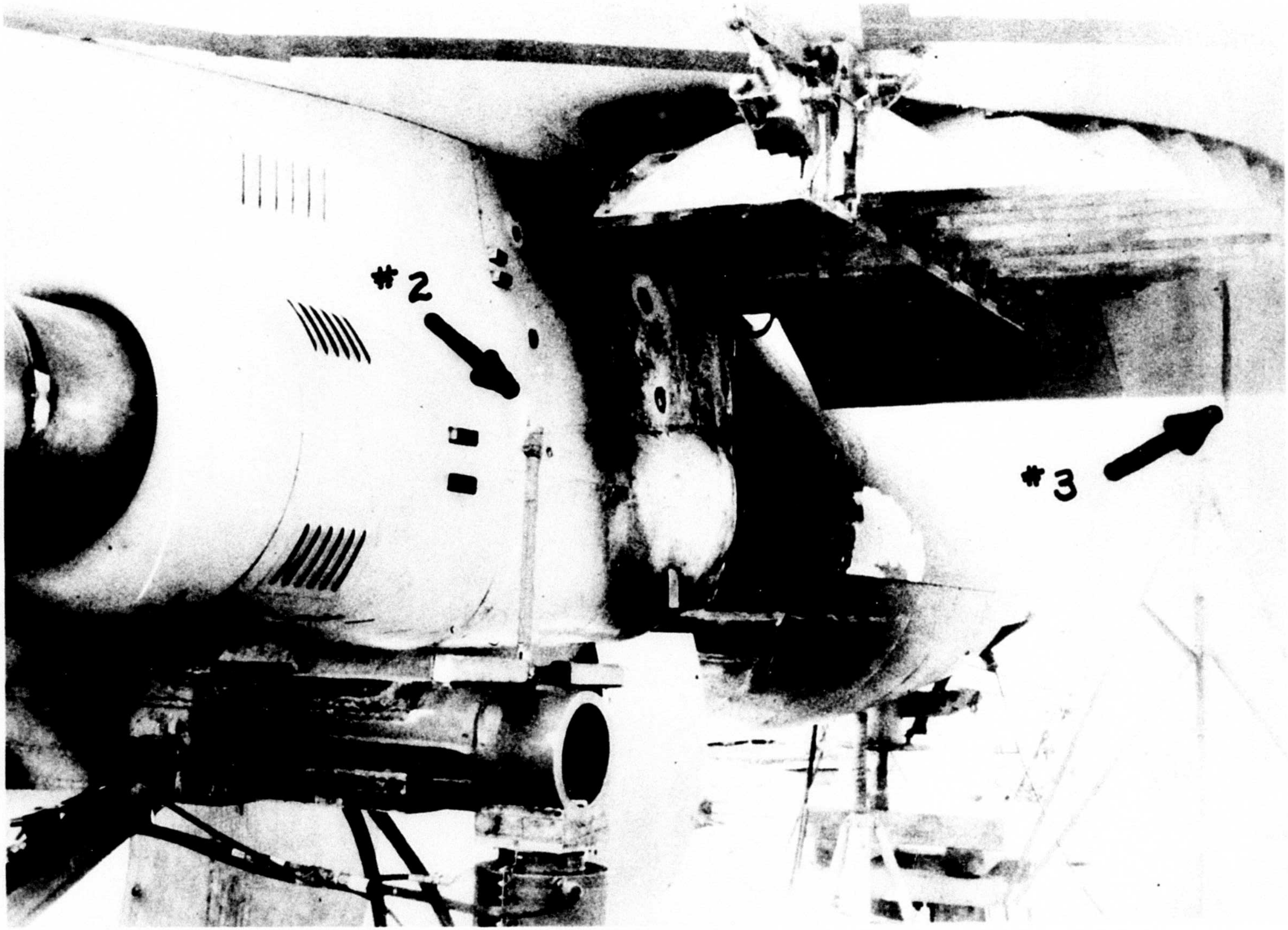

Figure 7 Microphone Location: General Electric Ground Test at NASA-Ames

Figure 8 Microphone Location: General Electric Ground Test at NASA-Ames

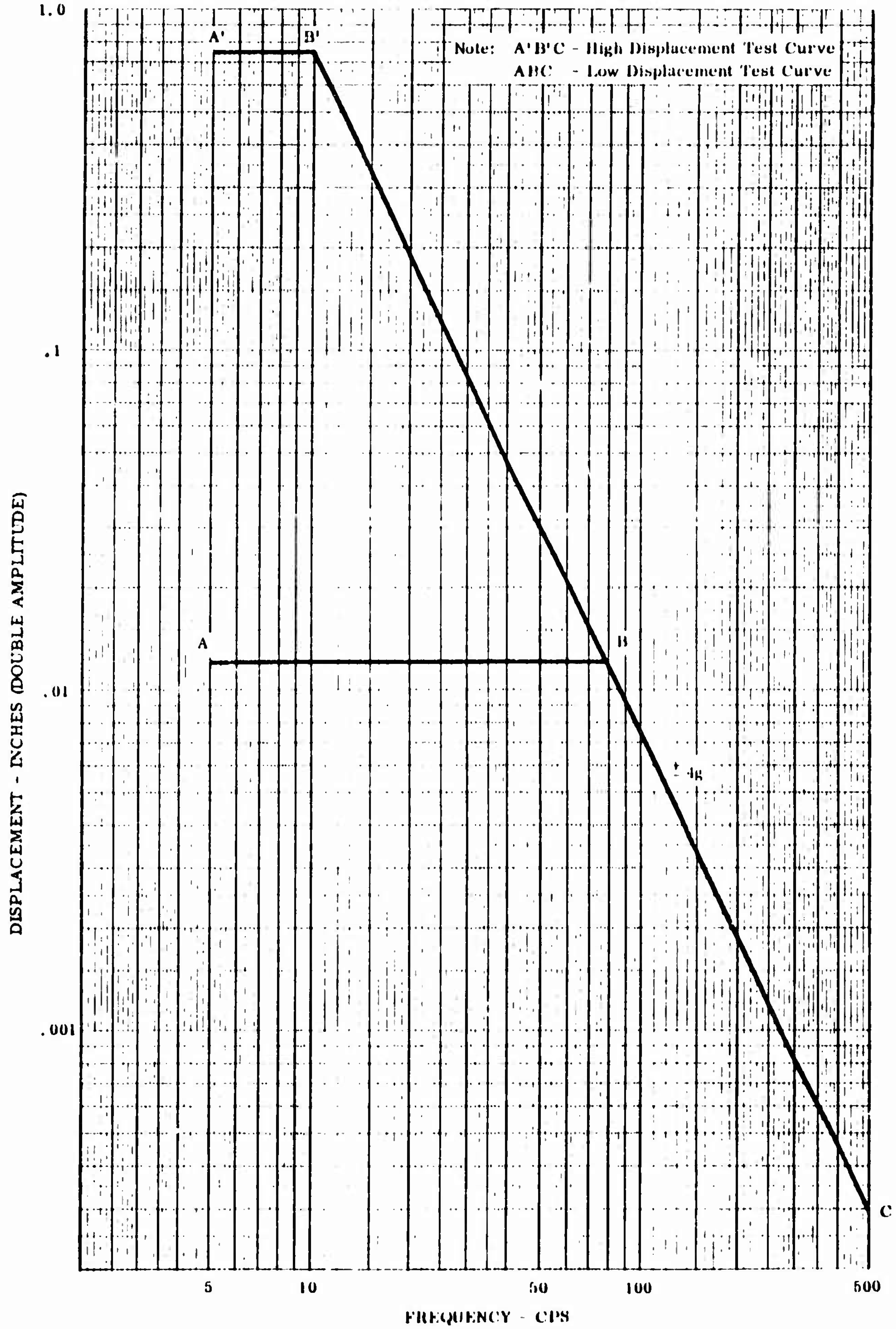

Figure 9 Qualification Test Vibration Amplitudes

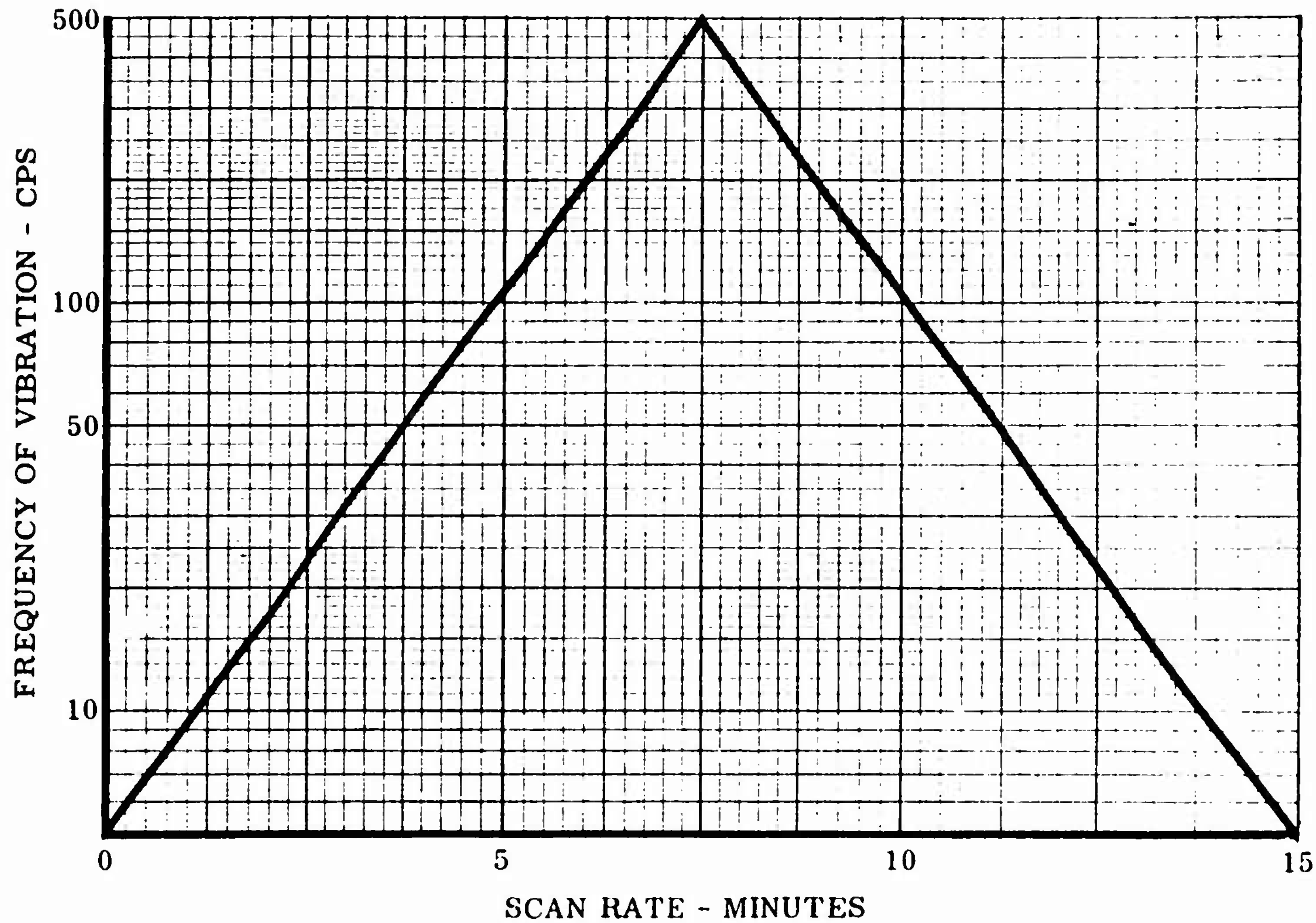

Figure 10 Cycling Test Scan Rate

TABLE 1

NEAR-FIELD MICROPHONE LOCATIONS FOR GENERAL ELECTRIC GROUND TEST

Position	Location
1	1 ft. above fuselage, 15 ft. forward of fan and (between snorkel inlets), and on aircraft centerline.
2	3 ft. below fan (on J-85 engine centerline), 6 ft. forward of fan centerline, and 1 ft. inboard of fan centerline.
3	1-1/2 ft. below fan plane, 4 ft. aft of fan centerline, and 1-1/2 ft. outboard of fan centerline.
4	4 ft. above fan plane, 18 ft. aft of fan centerline, and on fan centerline (laterally).

TABLE 2

SUMMARY OF DISCRETE FREQUENCY FAN NOISE
Sound Pressure Levels RE 0.0002 Microbar Approximately Corrected Data

Fan cps	Fan rpm	Frequency (cps)	Microphone Position 1	2	3	4	Remarks
11.25	675	120	-	-	-	92	
		400	-	-	-	92	
		800	-	-	-	84	
		1200	94	-	-	-	
		1600	97	-	-	-	Idle: 15 cps (925 rpm)
18.5	1110	660	-	122	110	-	
		1320	-	117	118	-	
		1980	-	118	119	-	
		2640	-	-	109	-	
23.2	1390	830	-	115	124	-	
		1660	-	-	113	-	
		2490	-	113	117	-	
		3320	-	-	112	-	
28.5	1710	1025	110	121	127	108	
		2050	101	115	125	103	
		3075	104	-	121	104	
		4100	101	-	122	101	
31.7	1900	1125	-	126	127	-	
		2250	-	122	126	-	
		3375	-	118	123	-	
		4500	-	117	122	-	
35.2	2110	1250	-	126	131	-	
		2500	-	120	125	-	
		3750	-	118	124	-	
		5000	-	115	120	-	
39	2340	1400	-	124	133	-	
		2800	-	124	129	-	
		4200	-	121	127	-	
		5600	-	117	-	-	
41.7	2500	1500	-	124	131	-	
		3000	-	121	129	-	
		4500	-	118	123	-	
		6000	-	117	-	-	
							T.O.: 44 cps (2640 rpm)

TABLE 3

VIBRATION TEST SCHEDULE

(Times shown refer to one axis of vibration)

Number of resonances	0	1	2
Total vibration time at resonance*	60 min	30 min	60 min
Cycling Time	120 min	150 min	120 min

*30 minutes at each resonance

In the absence of any resonance, vibrate the specimen at frequencies of 42 cps and 278 cps for 30 minutes each.

TABLE 4

TEST DURATION, TEMPERATURES AND VIBRATION AMPLITUDES

	Number of Resonances = 0		
	+68°F	-65°F	+160°F
Resonance ABC	8 Min	8 Min	8 Min
A'B'C	2 Min	2 Min	2 Min
Cycling	40 Min	40 Min	40 Min

	Number of Resonances = 1		
	+68°F	-65°F	+160°F
Resonance ABC	8 Min	8 Min	8 Min
A'B'C	2 Min	2 Min	2 Min
Cycling	50 Min	50 Min	50 Min

	Number of Resonances = 2		
	+68°F	-65°F	+160°F
Resonance ABC	8 Min	8 Min	8 Min
A'B'C	2 Min	2 Min	2 Min
Cycling	40 Min	40 Min	40 Min

NOTE: In the event a resonance occurs at a frequency such that the amplitude of vibration is the same for curves ABC and A'B'C the total test time shall be expended at the single amplitude.

4.0 CONCLUSIONS

4.1 ACOUSTICS

The analysis indicates that the proposed wing skin panels will not experience fatigue failure as a result of acoustic excitation sustained during the 250 hour design life of the aircraft.

4.2 VIBRATION

The vibration environment of the aircraft is expected to be similar to that of other jet aircraft of comparable rated thrust. Based on the anticipated vibration levels and the relatively short design life of the aircraft, components that may be subjected to significant oscillatory load should be investigated for fatigue on an individual basis by the design group involved.

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